

LETTER TO THE EDITOR

Detection of the linear SiC₃ and SiC₅ radicals in IRC+10216[★]

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ABSTRACT

We detected the linear ³Σ⁻ radicals SiC₃ and SiC₅ toward IRC+10216 using an ultrasensitive line survey gathered with the Yebes 40 m radio telescope. The derived column densities of *l*-SiC₃ and *l*-SiC₅ are $(3.6 \pm 0.4) \times 10^{12} \text{ cm}^{-2}$ and $(1.8 \pm 0.2) \times 10^{12} \text{ cm}^{-2}$, respectively. The linear SiC₃ radical is ~2 times less abundant than its singlet rhomboidal prolate isomer, for which we provide a new analysis based on recent sensitive observations in the Q band (7 mm), and at 3 and 2 mm with the IRAM 30 m telescope. The emission detected from these species arises from the cool external layers of the circumstellar envelope. We speculate whether ion-neutral routes involving SiC_{*n*}H_{*m*}⁺ cations or neutral-neutral reactions involving Si and SiC₂ could efficiently synthesize these species.

Key words. line: identification – molecular data – stars: carbon – circumstellar matter – stars: individual: IRC+10216

1. Introduction

The search for chemical complexity in space has received a significant boost in recent years thanks to the ultrasensitive line surveys in the Q band of the starless core TMC-1, the QUIJOTE¹ line survey (see, e.g., Cernicharo et al. 2021a,b, 2023a, 2024), and the envelope (IRC+10216) of the carbon-rich star CW Leo (see, e.g., Pardo et al. 2021, 2022, 2025a; Changala et al. 2022; Cernicharo et al. 2023b; Cabezas et al. 2023; Gupta et al. 2024). Since 2020 more than 90 molecules have been found with the Yebes 40 m radio telescope thanks to these ultrasensitive line surveys.

Since the detection of SiC₂ in 1984 by Thaddeus et al., this species has been observed toward the envelopes of carbon-rich stars through its rotational transitions in the millimeter and submillimeter domains. These lines provide information on the whole circumstellar envelope of these objects (Lucas et al. 1995; Cernicharo et al. 2010, 2018; Velilla-Prieto et al. 2023). The spatial distribution of SiC₂ derived from these high excitation lines is only known in detail toward IRC+10216, where it was observed with the Plateau de Bure interferometer (Guélin et al. 1993; Velilla-Prieto et al. 2019) and the CARMA and ALMA interferometers (Fonfría et al. 2014; Velilla-Prieto et al. 2015, 2023). Observations of three C-rich stars in four low-energy

SiC₂ transitions at an angular resolution of ~1'' revealed shell-like structures (Feng et al. 2023). A study with the IRAM 30 m telescope showed that SiC₂ is less abundant in denser envelopes, suggesting efficient incorporation of SiC₂ into dust grains (Massalkhi et al. 2018).

Apart from SiO, SiS, SiC₂, and Si₂C (Cernicharo et al. 2015), only a few molecules containing silicon have been found, all of which are present in IRC+10216. Silicon carbide (SiC) was detected in the external shells (300 R_{*} and beyond) of IRC+10216 (Cernicharo et al. 1989; Patel et al. 2013; Velilla-Prieto et al. 2019). It was also detected in the envelopes of several C-rich asymptotic giant branch stars by Massalkhi et al. (2018). Other silicon carbides such as the rhomboidal SiC₃ (Apponi et al. 1999a), SiC₄ (Ohishi et al. 1989), and SiC₆ (Pardo et al. 2025a) have been found in this source with column densities around 10–100 times lower than those of SiC₂ and Si₂C. SiH₄ was detected in the infrared by Keady & Ridgway (1993) and found to be formed at distances larger than 80 stellar radii (Monnier et al. 2000). Additional molecules containing silicon in this source are SiN (Turner 1992), SiH₃CH₃, and SiH₃CN (Cernicharo et al. 2017), and the two isomers SiNC and SiCN (Guélin et al. 2000, 2004), all in low abundances.

The detection of long SiC_{*n*} chains is expected based on the abundances found for the smaller members. In this Letter we report the detection of the linear ³Σ⁻ radicals SiC₃ and SiC₅ (hereafter referred to as *l*-SiC₃ and *l*-SiC₅). Linear SiC₃ is an isomer of the already detected rhomboidal closed shell species SiC₃ (hereafter referred to as *r*-SiC₃; Apponi et al. 1999a). The abundance of the newly detected molecules are compared to those of the other members of the SiC_{*n*} family and discussed in the context of the possible reactions leading to their formation.

[★] Based on observations carried out with the 40 m radio telescope of the Yebes Observatory (projects 19A010, 20A017, 20B014, 21A019, and commissioning observations), operated by the Spanish Geographic Institute (IGN, Ministerio de Transportes, Movilidad y Agenda Urbana). IRAM is supported by INSU/CNRS (France), MPG (Germany) and IGN (Spain).

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¹ Q-band Ultrasensitive Inspection Journey to the Obscure TMC-1 Environment.

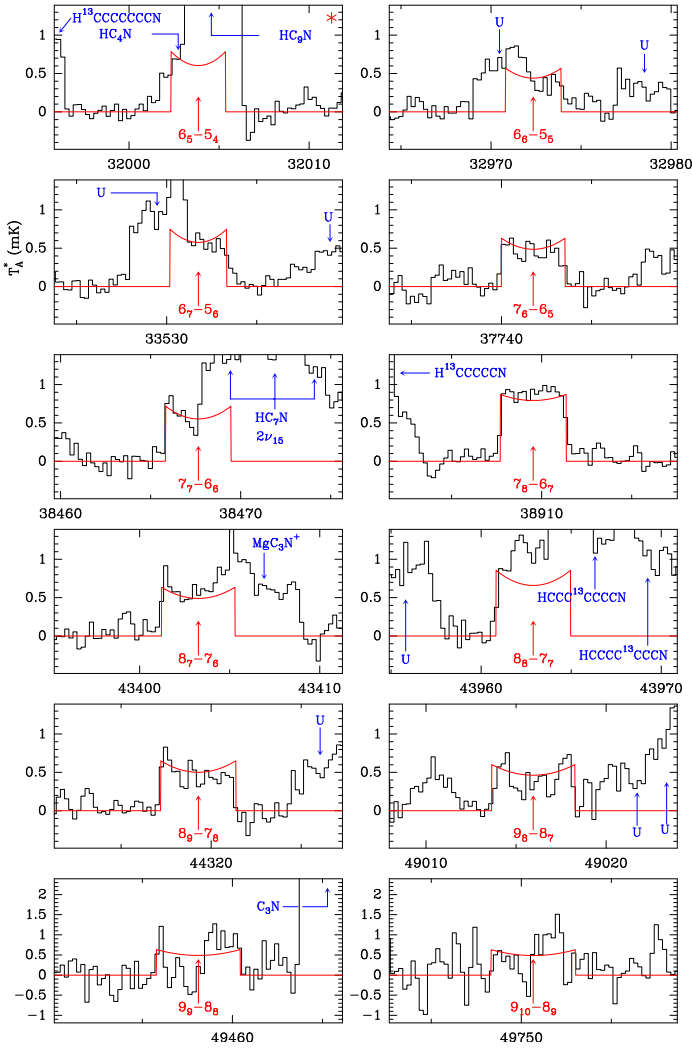


Fig. 1. Lines of the linear $^3\Sigma^-$ l -SiC₃ radical observed in this work, with their fitted line profile shown in red. Features from other species are labeled in blue. The abscissa corresponds to the rest frequency (in MHz) adopting a v_{LSR} of -26.5 km s^{-1} (Cernicharo et al. 2000). The ordinate corresponds to the antenna temperature corrected for telescope losses and atmospheric attenuation (in mK). Fully blended lines are indicated by a red star in the upper-right corner of the first panel. Quantum numbers are N (rotational quantum number) and J (total angular momentum, $J = N, N \pm 1$). They are written as N_J .

2. Observations

The data presented in this Letter come from a still ongoing 31–50 GHz spectral survey of IRC+10216 ($\alpha_{J2000} = 09^{\text{h}} 47^{\text{m}} 57.36^{\text{s}}$, $\delta_{J2000} = +13^{\circ} 16' 44.4''$) gathered in the framework of the Nanocosmos project². The data were obtained with the 40 meter antenna of Yebes Observatory (IGN, Spain). A total of 1360 hours of on-source telescope time was acquired between April 2019 and September 2024. The experimental setup is described in detail in Tercero et al. (2021).

The observing mode was position-switching with an off position at $300''$ in azimuth. Pointing corrections were obtained by observing the SiO masers of the nearby star R Leo, and errors were always within $5''$. The intensity scale of the final calibrated data is antenna temperature (T_A^*) corrected for atmospheric absorption using the ATM package (Pardo et al. 2001, 2025b).

Absolute calibration uncertainties are estimated to be within 10%. Although the primary spectral resolution is 38.1 kHz, the final spectrum was obtained by applying a six-channel box smoothing to the nominal spectrum. Hence, the spectral resolution is $\Delta\nu = 229 \text{ kHz}$. This line survey is 50–100 times more sensitive than previous surveys of this source at the same frequencies obtained with the Nobeyama 45 m radio telescope (Kawaguchi et al. 1995). The observations with the 30 m IRAM radio telescope have been described in Cernicharo et al. (2019).

3. Results

Line identification was achieved using the MADEX, CDMS, and JPL catalogs (Cernicharo 2012; Müller et al. 2005; Pickett et al. 1998). The datasets were fitted using the SHELL method of the GILDAS³ package. The global fitting procedure described by Pardo et al. (2025a) was adopted to derive the integrated intensities of the lines. Their typical U-shaped profiles, together with the expanding velocity of the envelope (14.5 km s^{-1} ; Cernicharo et al. 2000), enabled the detection of very weak lines emerging from IRC+10216.

Rotational line frequencies for l -SiC₃ and l -SiC₅ are available from laboratory experiments by McCarthy et al. (2000). Both species have a $^3\Sigma^-$ electronic ground state. A dipole moment of 4.8 D was calculated for l -SiC₃ in the same work. For l -SiC₅ we have assumed a dipole moment of 6.6 D (Müller et al. 2005). Both species have been implemented in MADEX (Cernicharo 2012). The frequency coverage and the large quantum numbers for the laboratory transitions guarantee very good frequency predictions, with uncertainties below a few kilohertz, in the Q band. The observed lines of l -SiC₃ are shown in Fig. 1, and those of l -SiC₅ are shown in Fig. 2. In spite of the presence of some lines blended with other features, the detection of l -SiC₃ is based on the detection of 11 lines, and that of l -SiC₅ in 22 lines. For both species, only a few lines are fully blended with strong features. These transitions were not considered for the analysis. Hence, the detection appears robust and permits a detailed analysis of the abundance of these species.

We used the observed integrated intensities given in Table A.1 to create rotation diagrams. For l -SiC₃ we derive $T_{\text{rot}} = 5.2 \pm 0.5 \text{ K}$ and $N = (3.6 \pm 0.5) \times 10^{12} \text{ cm}^{-2}$. For l -SiC₅ the results are $T_{\text{rot}} = 17.2 \pm 1.6 \text{ K}$ and $N = (1.8 \pm 0.3) \times 10^{12} \text{ cm}^{-2}$. These column densities are between those derived by Pardo et al. (2025a) for SiC₄ ($N = (7.3 \pm 1.1) \times 10^{12} \text{ cm}^{-2}$; $T_{\text{rot}} = 21.5 \pm 5 \text{ K}$) and SiC₆ ($N = (7.9 \pm 1.5) \times 10^{11} \text{ cm}^{-2}$; $T_{\text{rot}} = 19.5 \pm 2.1 \text{ K}$).

Laboratory spectroscopy for rhomboidal SiC₃ was obtained by McCarthy et al. (1999a) and Apponi et al. (1999b). Its column density in IRC+10216 was derived by Apponi et al. (1999a) from several lines in the millimeter domain to be $4 \times 10^{12} \text{ cm}^{-2}$. No new data on r -SiC₃ have been published since then. Hence, we analyze in Appendix B the data we have obtained in the 7 mm (Q band), 3 mm, and 2 mm frequency domains for this species. Two temperature components are found (see Fig. B.1), one with $T_{\text{rot}} = 15.8 \pm 0.9 \text{ K}$ and $N = (6.5 \pm 0.6) \times 10^{12} \text{ cm}^{-2}$. The rotational temperature for this component is similar to that found for l -SiC₅, SiC₄, and SiC₆. A second component is needed with a higher rotational temperature of $44 \pm 8 \text{ K}$ and a lower column density of $(2.1 \pm 0.5) \times 10^{12} \text{ cm}^{-2}$. The fact that r -SiC₃ has a C_{2v} symmetry with only a -type transitions (only $\Delta K_a = 0$ transitions are allowed) introduces significant different excitation con-

² <https://nanocosmos.iff.csic.es/>

³ <http://www.iram.fr/IRAMFR/GILDAS>

The chemistry of SiC₃ in IRC+10216 has been investigated to some extent. MacKay & Charnley (1999) predicted a sizable column density for SiC₃ (without distinction of the isomer) of $4.6 \times 10^{12} \text{ cm}^{-2}$. Although not specifically discussed by these authors, in their model SiC₃ most likely arises from the photodissociation of SiC₄, which was predicted to be five times more abundant than SiC₃. Photodissociation of SiC₄ is, however, unlikely to be the main source of SiC₃ because the observed column density of SiC₄ ($7.3 \times 10^{12} \text{ cm}^{-2}$; Pardo et al. 2025a) is similar to the sum of those derived for *r*-SiC₃ ($4.3 \times 10^{12} \text{ cm}^{-2}$; Apponi et al. 1999a) and *l*-SiC₃ ($3.6 \times 10^{12} \text{ cm}^{-2}$; this study).

Other routes leading to SiC₃ in current astrochemical databases (Millar et al. 2024; Wakelam et al. 2024) involve the dissociative recombination with electrons of Si-bearing hydrocarbon cations SiC_{*n*}H_{*m*}⁺ formed by ion-neutral reactions involving Si or Si⁺. The reaction between Si⁺ and C₂H₂ has been studied experimentally, and it has been found that the cation SiC₂H⁺ is formed (Wlodek et al. 1991). It would be interesting to investigate how Si⁺ reacts with polyynes and cyanopolyynes and their radicals, particularly whether radiative association proceeds rapidly for long carbon chains, as observed for metals such as Mg⁺, Na⁺, and Al⁺ (Petrie 1996; Dunbar & Petrie 2002; Cabezas et al. 2023; Cernicharo et al. 2023b). The formation of cationic complexes of the type SiC_{*n*}H₂⁺, SiC_{*n*}H⁺, SiHC_{*n*}N⁺, and SiC_{*n*}N⁺ followed by their dissociative recombination with electrons could efficiently form the SiC_{*n*} chains.

Neutral-neutral reactions could also allow SiC_{*n*} chains to be synthesized. For example, SiC₃ could be formed in the reactions Si + C₃H and SiC₂ + CH, while SiC₅ could be produced by the reactions Si + C₅H, SiC₂ + C₃H, and SiC₄ + CH. If these reactions are barrierless and proceed through H atom elimination, they can efficiently form SiC₃ and SiC₅ because they involve reactants that are known or expected to be abundant in the outer circumstellar layers of IRC+10216. However, none of them have been studied either experimentally or theoretically. Reactions of Si with unsaturated closed electronic shell hydrocarbons have been measured to be rapid at low temperatures (Canosa et al. 2001), making it likely that Si reacts efficiently with C₃H and C₅H. We note that the reaction Si + C₂H₂ is endothermic for the channel SiCCH + H (Kaiser & Gu 2009), which explains why SiCCH (whose rotational spectrum is known; Apponi et al. 2000; McCarthy et al. 2001) has not been detected in IRC+10216. Other Si-bearing molecules with well-characterized rotational spectra that could result from the various ion-neutral or neutral-neutral routes at work in IRC+10216 are H₂CSi, H₂CCSi, H₂CCCSi, and H₂CCCCSi (Izuha et al. 1996; McCarthy & Thaddeus 2002; McCarthy et al. 2024). However, none of them is found in our data at 7, 3, and 2 mm.

In summary, *l*-SiC₃ and *l*-SiC₅ have been found in IRC+10216, completing the family of silicon carbon chains from SiC up to SiC₆. The column densities of these species are $(3.6 \pm 0.4) \times 10^{12} \text{ cm}^{-2}$ and $(1.8 \pm 0.2) \times 10^{12} \text{ cm}^{-2}$, respectively. They are expected to be formed in the outer envelope. The abundance ratio *l*-SiC₃ over *l*-SiC₅ is ~ 2 . These species are 17 and 33 times less abundant than SiC (Cernicharo et al. 1989) and have a similar abundance to that of SiC₆ (Pardo et al. 2025a). We expect to detect heavier members of the SiC_{*n*} family with future improved data of IRC+10216.

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Table A.1. Derived line parameters for the lines of l -SiC₃ and l -SiC₅ in the Q band.

Transition ^a	Frequency ^b (MHz)	E_{upp} ^b (K)	S^d	$\int T_A^* dv^e$ (mK kms ⁻¹)	T_{cen}^f (mK)	T_{horn}^g (mK)	σ^h (mK)	Notes
<i>l</i> -SiC ₃								
6 ₅ -5 ₄	32003.850±0.003	6.4	4.95				0.12	A
6 ₆ -5 ₅	32972.345±0.001	5.3	5.83	13.56±1.35	0.43	0.56	0.16	
6 ₇ -5 ₆	33531.757±0.004	5.9	6.89	17.86±1.78	0.57	0.74	0.10	
7 ₆ -6 ₅	37741.763±0.004	8.2	5.95	15.02±1.50	0.48	0.63	0.15	
7 ₇ -6 ₆	38467.643±0.001	7.2	6.86	17.22±1.72	0.55	0.71	0.16	
7 ₈ -6 ₇	38909.532±0.004	7.8	7.91	23.14±2.31	0.79	0.87	0.14	B
8 ₇ -7 ₆	43403.260±0.004	10.3	6.95	15.18±1.51	0.48	0.63	0.20	
8 ₈ -7 ₇	43962.898±0.002	9.3	7.88	20.50±2.05	0.65	0.85	0.18	
8 ₉ -7 ₈	44319.288±0.005	9.9	8.92	15.58±1.55	0.50	0.65	0.20	
9 ₈ -8 ₇	49015.957±0.005	12.6	7.96	14.42±1.44	0.46	0.60	0.30	
9 ₉ -8 ₈	49458.104±0.002	11.7	8.89	15.16±1.51	0.48	0.63	0.39	
9 ₁₀ -8 ₉	49750.661±0.005	12.3	9.93	15.09±1.50	0.48	0.63	0.15	
<i>l</i> -SiC ₅								
17 ₁₇ -16 ₁₆	31310.218±0.004	13.4	16.94	8.67±0.87	0.24	0.42	0.11	
17 ₁₈ -16 ₁₇	31834.929±0.005	14.3	17.95	10.34±1.03	0.29	0.50	0.11	
18 ₁₇ -17 ₁₆	32589.599±0.006	17.2	16.99	8.32±0.83	0.21	0.35	0.09	
18 ₁₈ -17 ₁₇	33151.956±0.005	15.0	17.94				0.10	A
18 ₁₉ -17 ₁₈	33642.330±0.006	15.9	18.95	7.97±0.80	0.23	0.38	0.10	
19 ₁₈ -18 ₁₇	34468.700±0.007	18.9	17.99	8.71±0.87	0.25	0.42	0.09	
19 ₁₉ -18 ₁₈	34993.686±0.006	16.7	18.95	9.37±0.94	0.27	0.45	0.11	
19 ₂₀ -18 ₁₉	35452.518±0.007	17.6	19.96				0.10	A
20 ₁₉ -19 ₁₈	36344.744±0.008	20.6	18.99	13.14±1.31	0.37	0.64	0.09	
20 ₂₀ -19 ₁₉	36835.410±0.007	18.5	19.95	11.42±1.14	0.32	0.55	0.10	
20 ₂₁ -19 ₂₀	37265.252±0.008	19.4	20.96	13.66±1.37	0.39	0.66	0.11	
21 ₂₀ -20 ₁₉	38217.987±0.010	22.4	19.99	11.78±1.18	0.33	0.57	0.14	
21 ₂₁ -20 ₂₀	38677.125±0.008	20.3	20.95	11.59±1.16	0.33	0.56	0.10	
21 ₂₂ -20 ₂₁	39080.309±0.009	21.3	21.96	12.98±1.30	0.37	0.63	0.11	
22 ₂₁ -21 ₂₀	40088.669±0.011	24.4	20.99	10.42±1.04	0.30	0.50	0.11	
22 ₂₂ -21 ₂₁	40518.833±0.010	22.3	21.95	11.14±1.11	0.31	0.54	0.10	
22 ₂₃ -21 ₂₂	40897.483±0.011	23.3	22.96	12.50±1.25	0.35	0.60	0.12	
23 ₂₂ -22 ₂₁	41957.011±0.013	26.4	21.99	12.16±1.22	0.34	0.59	0.12	
23 ₂₃ -22 ₂₂	42360.532±0.011	24.3	22.96	10.61±1.06	0.30	0.51	0.10	
23 ₂₄ -22 ₂₃	42716.584±0.012	25.3	23.96	10.51±1.05	0.30	0.51	0.11	
24 ₂₃ -23 ₂₂	43823.220±0.014	28.5	22.99				0.14	A
24 ₂₄ -23 ₂₃	44202.223±0.013	26.4	23.96				0.14	A
24 ₂₅ -23 ₂₄	44537.439±0.014	27.5	24.97	8.71±0.87	0.25	0.42	0.14	
25 ₂₄ -24 ₂₃	45687.484±0.016	30.7	23.99	11.83±1.18	0.33	0.57	0.16	
25 ₂₅ -24 ₂₄	46043.904±0.015	28.6	24.96	14.99±1.50	0.48	0.62	0.18	
25 ₂₆ -24 ₂₅	46359.890±0.016	29.7	25.97	9.72±0.97	0.27	0.47	0.17	
26 ₂₅ -25 ₂₄	47549.976±0.018	32.9	24.99				0.24	A
26 ₂₆ -25 ₂₅	47885.576±0.017	30.9	25.96				0.20	A

Notes. ^(a) Quantum numbers are N (rotational quantum number) and J (total angular momentum, $J = N, N+1, N-1$). They are written as N_J . ^(b) Calculated frequency from the laboratory data of McCarthy et al. (2000). The adopted source velocity is of -26.5 kms⁻¹ (Cernicharo et al. 2000).

^(c) Energy of the upper level in K.

^(d) Line strength.

^(e) Integrated line intensity in mK kms⁻¹. Adopted uncertainty is 10%.

^(f) Antenna temperature at line center in mK.

^(g) Antenna temperature at line horn in mK.

^(h) Measured data noise (1σ) in mK.

^(A) Heavily blended. Line parameters can not be derived.

^(B) Probably blended with a unidentified line.

Appendix A: Line parameters

Although the data presented in this work in the Q band correspond to windows of ± 8 MHz around the centre frequencies, the data were analysed over a ± 100 MHz window to derive accurate sensitivities and baselines. The derived line parameters for the l -SiC₃ and l -SiC₅ species are given in Table A.1. The lines of l -SiC₃ and l -SiC₅ are shown in Fig. 1 and 2, respectively. The same method has been used for all the lines of the rhomboidal isomer of SiC₃ observed with the Yebes 40m radio telescope at 7 mm, and the IRAM 30m telescope at 3 and 2 mm. The derived line parameters for this species are given in Table B.1 and the observed lines are shown in Fig. B.2.

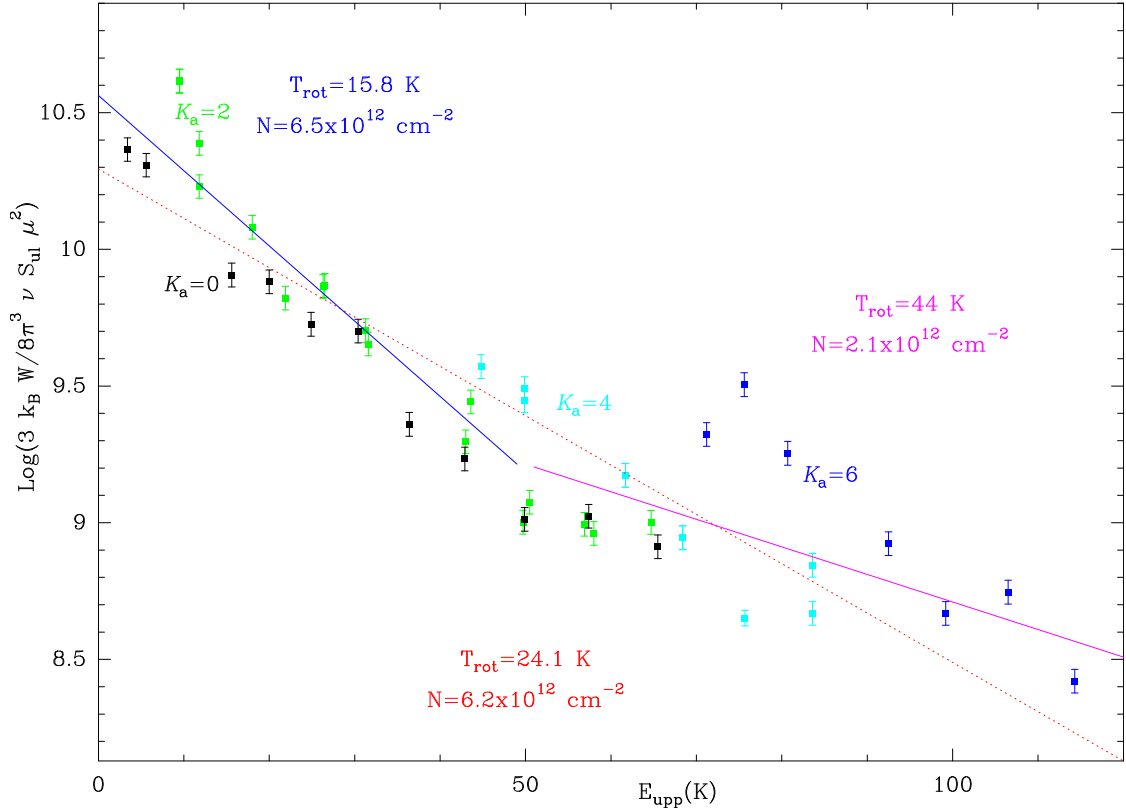


Fig. B.1. Rotational diagram for the lines of r -SiC₃. The blue line correspond to a fit to all transitions with energy of their upper level lower than 50 K. The purple one corresponds to the fit to all data with upper level energies above 50 K. The dashed red line corresponds to a global fit to all the data and represents an averaged temperature and column density. The data for each K_a is represented by the same color (black for $K_a=0$, green for $K_a=2$, cyan for $K_a=4$ and blue for $K_a=6$).

Appendix B: Rhomboidal SiC₃

The rhomboidal isomer of SiC₃ was discovered in IRC+10216 by [Apponi et al. \(1999a\)](#) from the observation of seven lines in the 3 mm domain. Transitions of this species at 2mm were also observed by [Cernicharo et al. \(2000\)](#). Here, we report the detection of 45 rotational transitions of this isomer with upper energy levels of up to 114 K. Line parameters were derived in a similar way to those of l -SiC₃ and l -SiC₅ and are given in Table B.1. The rotational analysis of these data is shown in Fig. B.1 (see below).

Most observed lines have an excellent S/N and exhibit U-shaped line profiles (see Fig. B.2). This implies that the emerging lines are formed in the external layers of the envelope. From the observed intensities we can estimate from a rotation diagram (see Fig. B.1) the rotational temperature and column density of the molecule. A global fit to all the data provides $T_{rot}=24.1\pm 1.2$ K and $N=(6.2\pm 1.2)\times 10^{12}$ cm⁻². The fit is shown as a dashed red line in Fig. B.1. However, from the observed intensities it appears that for the lines with upper level energies below 50 K ($K_a=0, 2$, and 4) the rotational temperature is considerably lower, $T_{rot}=15.8\pm 0.9$ K. The column density for this gas component is $N=(6.5\pm 0.6)\times 10^{12}$ cm⁻². The fit is shown in Fig. B.1 as a blue line. The rotational temperature for this gas component is similar to that of l -SiC₅, SiC₄ and SiC₆. Finally, a warmer gas component is found for transitions with energies of their upper levels above 50 K ($K_a\geq 4$). The derived rotational temperature for this component is 44 ± 8 K and its column density is $(2.1\pm 0.5)\times 10^{12}$ cm⁻² (purple line in Fig. B.1). These results are in reasonable agreement with those derived by [Apponi et al. \(1999a\)](#) from a more reduced number of lines and with lower sensitivities.

The lack of collisional rates for the SiC₃ isomers avoids a detailed study of their excitation conditions. However, as indicated previously by [Apponi et al. \(1999a\)](#), the symmetry of r -SiC₃ and the fact that only $\Delta K_a=0$ radiative transitions are allowed, introduce some peculiarities in the population mechanisms of its energy levels. Collisions could connect all levels independently of the value of K_a , while radiation could connect only levels within a K-ladder. Hence, we expect to have low rotational temperatures within the K-ladders, and higher rotational temperatures across K-ladders. This is following what is represented in Fig. B.1 and the intensities provided in Table B.1. The colors for the data points in this figure corresponds to the different values of K_a . For each color, i.e., for each K_a , the slope of the data is practically the same. The data for different values of K_a are shifted in energy (compare for example $K_a=4$ and $K_a=6$), but keep the same slope (rotational temperature). The data for $K_a=0$ and 2 can be fitted simultaneously and provide a rotational temperature of 15.7 ± 0.6 K. For the $K_a=4$ and $K_a=6$ ladders the derived rotational temperature is of 17.8 ± 1.4 K and 18.6 ± 1.6 K, respectively. Hence, the average intra-ladder rotational temperature is ~ 17 K, while the cross-ladder is ~ 44 K. The intra-ladder temperature is very similar to that obtained for the rotational temperatures of the linear chains l -SiC₃, SiC₄, l -SiC₅, and SiC₆.

Table B.1. Derived line parameters for the lines of rhomboidal SiC₃ at 7, 3, and 2 mm.

Transition ^a	Frequency ^b (MHz)	E _{upp} ^b (K)	S ^d	∫ T _A [*] dv ^e (mK kms ⁻¹)	T _{cen} ^f (mK)	T _{horn} ^g (mK)	σ ^h (mK)	Notes
3 _{0,3} – 2 _{0,2}	34934.203±0.001	3.4	3.00	34.3±3.4	1.10	1.42	0.10	
3 _{2,2} – 2 _{2,1}	35008.949±0.001	9.5	1.67	34.2±3.4	1.10	1.44	0.10	A
3 _{2,1} – 2 _{2,0}	35083.884±0.001	9.5	1.67	34.2±3.4	1.10	1.49	0.10	A
4 _{0,4} – 3 _{0,3}	46491.687±0.001	5.6	4.00	70.9±7.0	2.09	3.35	0.16	
4 _{2,3} – 3 _{2,2}	46663.838±0.001	11.8	3.00	64.2±6.4	1.79	3.20	0.17	
4 _{2,2} – 3 _{2,1}	46850.811±0.001	11.8	3.00	44.8±4.4	1.44	1.85	0.18	
6 _{2,4} – 5 _{2,3}	70579.646±0.002	18.0	5.33	169.9±16.9	5.47	7.19	2.00	
7 _{0,7} – 6 _{0,6}	80662.322±0.003	15.6	6.98	204.4±20.4	6.58	8.53	0.67	
7 _{2,6} – 6 _{2,5}	81540.082±0.002	21.8	6.43				0.89	B
7 _{6,2} – 6 _{6,1}	81734.532±0.004	71.2	1.86	29.3±5.5	1.77	2.30	0.96	C
7 _{6,1} – 6 _{6,0}	81734.532±0.004	71.2	1.86				0.96	D
7 _{4,4} – 6 _{4,3}	81777.540±0.002	40.4	4.72				0.96	B
7 _{4,3} – 6 _{4,2}	81777.859±0.002	40.4	4.72				0.96	B
7 _{2,5} – 6 _{2,4}	82563.549±0.003	21.9	6.43	163.4±16.3	5.26	6.84	0.83	
8 _{0,8} – 7 _{0,7}	91844.820±0.004	20.0	7.98	293.7±29.3	7.81	15.61	0.51	
8 _{2,7} – 7 _{2,6}	93125.636±0.002	26.3	7.50	273.6±27.3	7.27	14.54	0.44	A
8 _{6,3} – 7 _{6,2}	93420.830±0.004	75.6	3.50	112.3±11.2	3.41	5.11	0.42	
8 _{6,2} – 7 _{6,1}	93420.830±0.004	75.6	3.50				0.42	D
8 _{4,5} – 7 _{4,4}	93484.045±0.003	44.8	6.00	224.4±22.4	6.45	10.96	0.42	
8 _{4,4} – 7 _{4,3}	93484.920±0.003	44.8	6.00				0.42	D
8 _{2,6} – 7 _{2,5}	94634.686±0.004	26.5	7.50	285.1±28.5	8.19	13.92	0.56	
9 _{0,9} – 8 _{0,8}	102916.115±0.004	24.9	8.97	291.2±29.1	8.37	14.22	0.71	
9 _{2,8} – 8 _{2,7}	104686.180±0.002	31.3	8.55	272.0±27.2	7.82	13.28	1.00	
9 _{6,4} – 8 _{6,3}	105111.104±0.005	80.7	5.00	114.1±11.4	3.28	5.57	1.00	
9 _{6,3} – 8 _{6,2}	105111.104±0.005	80.7	5.00				1.00	D
9 _{4,6} – 8 _{4,5}	105199.949±0.003	49.9	7.22	142.5±14.2	4.10	6.96	1.00	
9 _{4,5} – 8 _{4,4}	105202.048±0.003	49.9	7.22	128.3±12.8	4.54	11.50	1.00	
9 _{2,7} – 8 _{2,6}	106791.028±0.004	31.6	8.55	252.6±25.2	7.26	12.34	1.10	
10 _{0,10} – 9 _{0,9}	113882.012±0.005	30.4	9.96	368.5±36.8	9.81	19.58	1.50	
11 _{0,11} – 10 _{0,10}	124755.032±0.006	36.4	10.95	216.2±21.6	5.75	11.49	2.00	
11 _{2,10} – 10 _{2,9}	127720.669±0.003	43.0	10.63	187.7±18.7	4.99	9.97	1.10	
11 _{6,6} – 10 _{6,5}	128505.569±0.005	92.5	7.73	116.6±11.6	3.54	5.31	1.10	
11 _{6,5} – 10 _{6,4}	128505.570±0.005	92.5	7.73				1.10	D
11 _{4,8} – 10 _{4,7}	128663.730±0.003	61.7	9.55	128.7±12.9	3.49	6.63	1.20	
11 _{4,7} – 10 _{4,6}	128672.788±0.003	61.7	9.55	128.7±12.9	3.49	6.63	1.20	
11 _{2,9} – 10 _{2,8}	131315.143±0.005	43.6	10.64	273.9±27.3	7.28	14.55	0.70	
12 _{0,12} – 11 _{0,11}	135552.619±0.007	42.9	11.95	199.0±19.9	4.23	12.69	0.51	
12 _{2,11} – 11 _{2,10}	139189.193±0.003	49.7	11.66	118.4±11.8	2.50	7.55	0.78	
12 _{6,7} – 11 _{6,6}	140210.760±0.006	99.2	9.00	85.5±8.5	2.75	3.58	0.81	
12 _{6,6} – 11 _{6,5}	140210.763±0.005	99.2	9.00				0.81	D
12 _{4,9} – 11 _{4,8}	140413.124±0.003	68.4	10.67	96.1±9.6	2.27	5.67	0.73	
12 _{4,8} – 11 _{4,7}	140430.055±0.003	68.4	10.67	96.1±9.6	2.27	5.67	0.73	
12 _{2,10} – 11 _{2,9}	143645.312±0.006	50.5	11.67	146.1±14.6	3.10	9.31	0.58	
13 _{0,13} – 12 _{0,12}	146294.448±0.007	49.9	12.94	143.4±14.3	3.05	9.14	0.67	
13 _{2,12} – 12 _{2,11}	150621.962±0.004	56.9	12.68	139.3±13.9	2.96	8.88	0.70	
13 _{6,8} – 12 _{6,7}	151921.925±0.006	106.5	10.23	128.2±12.8	2.72	8.17	0.82	
13 _{6,7} – 12 _{6,6}	151921.933±0.006	106.5	10.23				0.82	D
13 _{4,10} – 12 _{4,9}	152174.858±0.003	75.7	11.77	59.4±3.9	1.57	3.14	0.85	
13 _{4,9} – 12 _{4,8}	152204.839±0.003	75.7	11.77				0.85	B
13 _{2,11} – 12 _{2,10}	155989.821±0.006	58.0	12.70	134.5±13.4	2.86	8.57	0.91	
14 _{0,14} – 13 _{0,13}	156999.640±0.007	57.4	13.94	171.8±17.1	3.65	10.95	0.60	
14 _{2,13} – 13 _{2,12}	162016.850±0.003	64.7	13.70	165.6±16.6	3.54	10.50	0.94	
14 _{6,9} – 13 _{6,8}	163639.571±0.006	114.3	11.43	73.3±7.3	2.36	3.00	0.78	
14 _{6,8} – 13 _{6,7}	163639.589±0.006	114.3	11.43				0.78	D
14 _{4,11} – 13 _{4,10}	163949.103±0.004	83.6	12.86	73.1±7.3	2.35	3.16	0.95	
14 _{4,10} – 13 _{4,9}	163999.813±0.004	83.6	12.86	109.7±10.9	3.53	4.59	0.95	
15 _{0,15} – 14 _{0,14}	167684.621±0.007	65.5	14.93	151.9±15.1	3.23	9.68	1.20	

Notes. ^(a) Quantum numbers are $J, K_a,$ and $K_c.$ ^(b) Calculated frequency from the laboratory data of McCarthy et al. (2000). The adopted source velocity is of -26.5 kms^{-1} (Cernicharo et al. 2000). ^(c) Energy of the upper level in K. ^(d) Line strength. ^(e) Integrated line intensity in mK kms^{-1} . Adopted uncertainty is 10%. ^(f) Antenna temperature at line center in mK. ^(g) Antenna temperature at line horn in mK. ^(h) Measured data noise (1σ) in mK. ^(A) Line partially blended with another feature. ^(B) Heavily blended. Line parameters can not be derived. ^(C) Upper limit. ^(D) Unresolved doublet.

